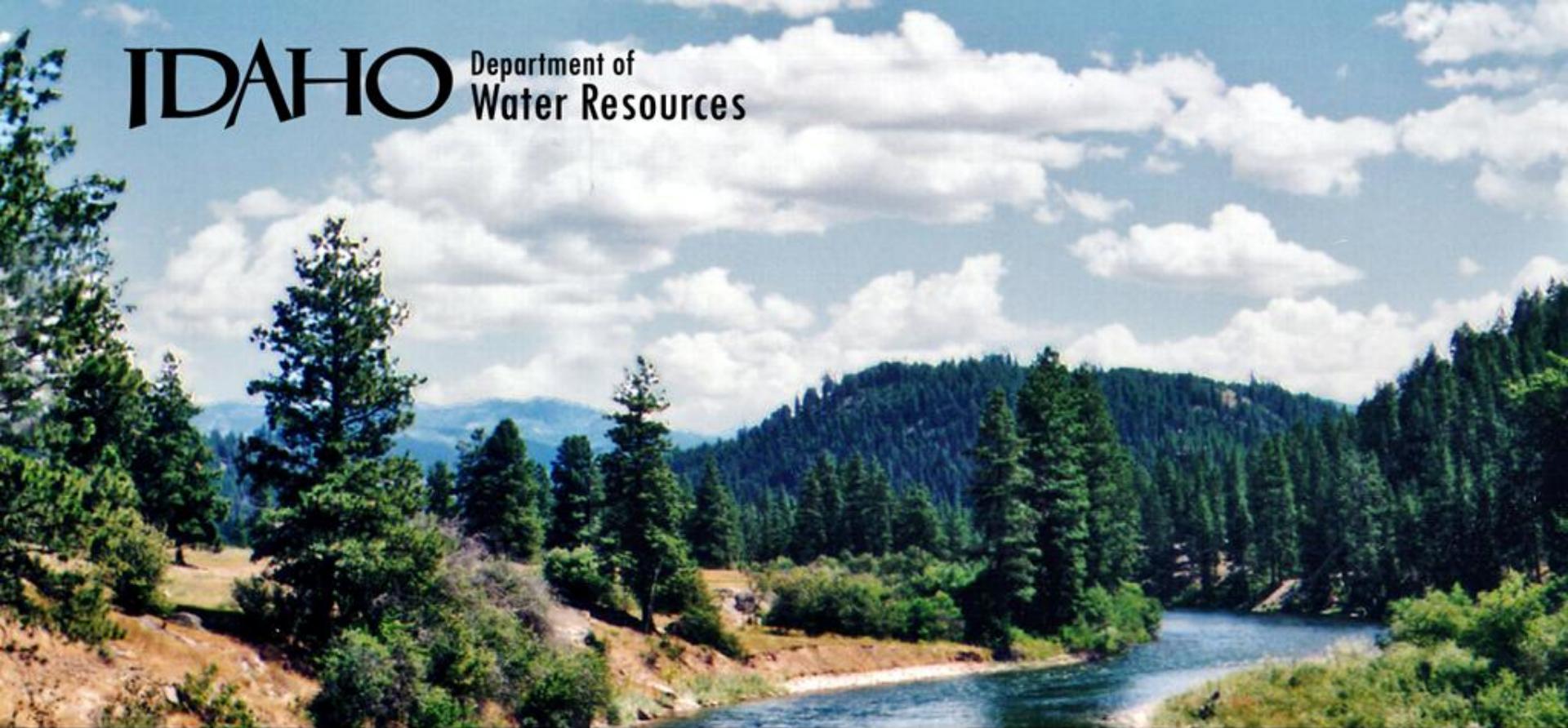




Department of
Water Resources



Wood River Groundwater Model Development: Evapotranspiration – METRIC, NDVI, and Interpolation for missing data

Presented by Mike McVay, P.E., P.G.
ESHMC May 6, 2014



General Techniques for ET Estimation

Two general techniques have been used to estimate ET:

1. Remote Sensing – Data collected by satellites is used in conjunction with weather-station data to estimate Growing-Season ET based on energy balance principles.
2. Traditional Calculation – Land-use data is used in conjunction with weather-station data to estimate Winter-Season ET using the ASCE standardized Penman-Monteith regression equation.

Winter ET Estimation

Winter ET estimates are calculated using the ASCE standardized Penman-Monteith regression equation (tabulated in ET Idaho). The issues that make this method less appealing for growing-season months are not applicable to Winter ET.

1. Winter ET a function of cover, not crop.
2. Irrigation practices and vegetative health irrelevant for winter ET.

Picabo	Nov	Dec	Jan	Feb	Mar
100% impervious	0	0	0	0	0
21% grass turf (lawns), irrigated	0.21	0.11	0.14	0.23	0.45
51% grass turf (lawns), irrigated	0.21	0.11	0.14	0.23	0.45
80% grass turf (lawns), irrigated	0.21	0.11	0.14	0.23	0.45
Alfalfa Less Frequent Cuttings	0.47	0.29	0.36	0.58	0.88
Bare Soil	0.4	0.28	0.36	0.57	0.81
Cottonwoods	0.32	0.2	0.25	0.39	0.71
Grass Pasture - high management	0.21	0.11	0.14	0.23	0.45
Mulched Soil, incl grain stubble	0.3	0.2	0.25	0.39	0.67
Open Water - shallow systems	0.68	0.29	0.34	0.63	1.32
Range Grass - early short season	0.3	0.2	0.25	0.39	0.7
Sage Brush	0.3	0.2	0.25	0.39	0.7
Spring Grain Irrigated	0.3	0.2	0.25	0.39	0.69
Sweet Corn Late Plant	0.42	0.29	0.36	0.58	0.88
Wetlands - narrow stands	0.32	0.2	0.25	0.39	0.71
Willows	0.33	0.2	0.25	0.39	0.72
Winter Grain	0.44	0.28	0.35	0.57	1.07

Average ET rates (mm/day)

Land Use and Winter ET

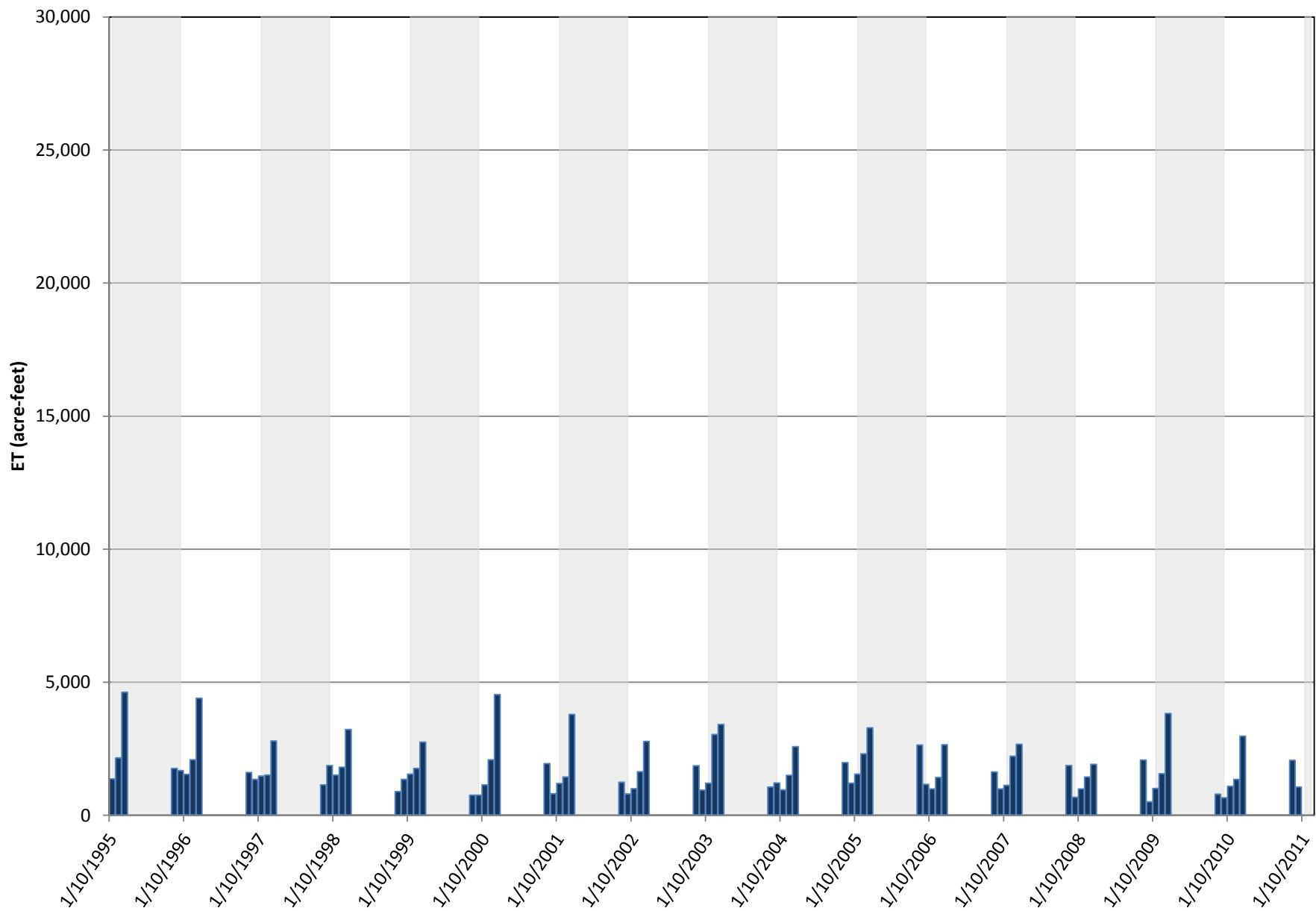
Year	1995	1996	1997	1998	1999	2000	2001	2002
Land Cover	2001 nlcd							

Year	2003	2004	2005	2006	2007	2008	2009	2010
Land Cover	2005 cdl	2005 cdl	2005 cdl	2006 nlcd	2007 cdl	2008 cdl	2009 cdl	2010 cdl

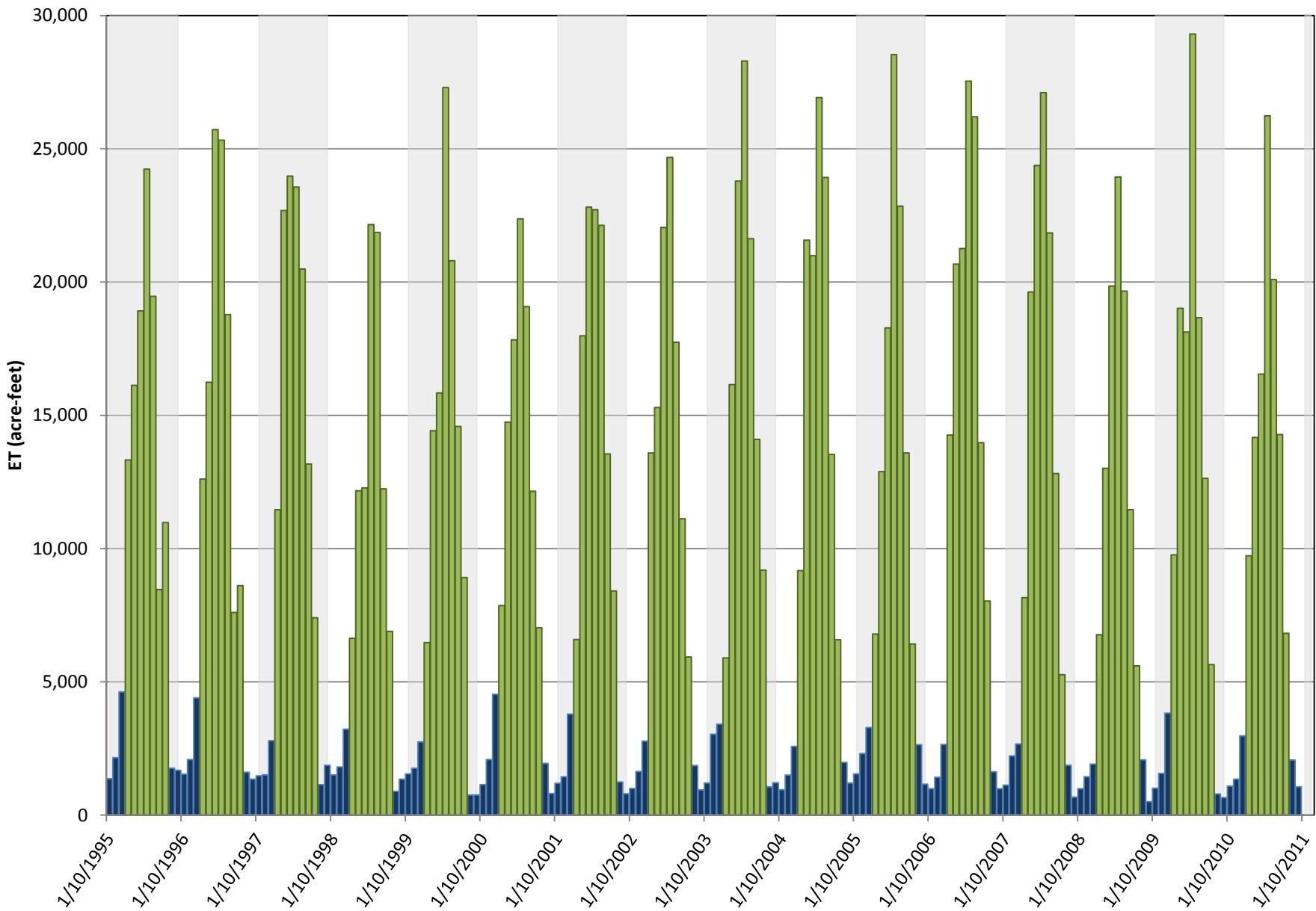
nlcd – National Land Cover Database, Multi-Resolution Land Consortium

cdl – Cropland Data Layer, National Agricultural Statistics Service

Big Wood Winter ET



Big Wood Monthly ET

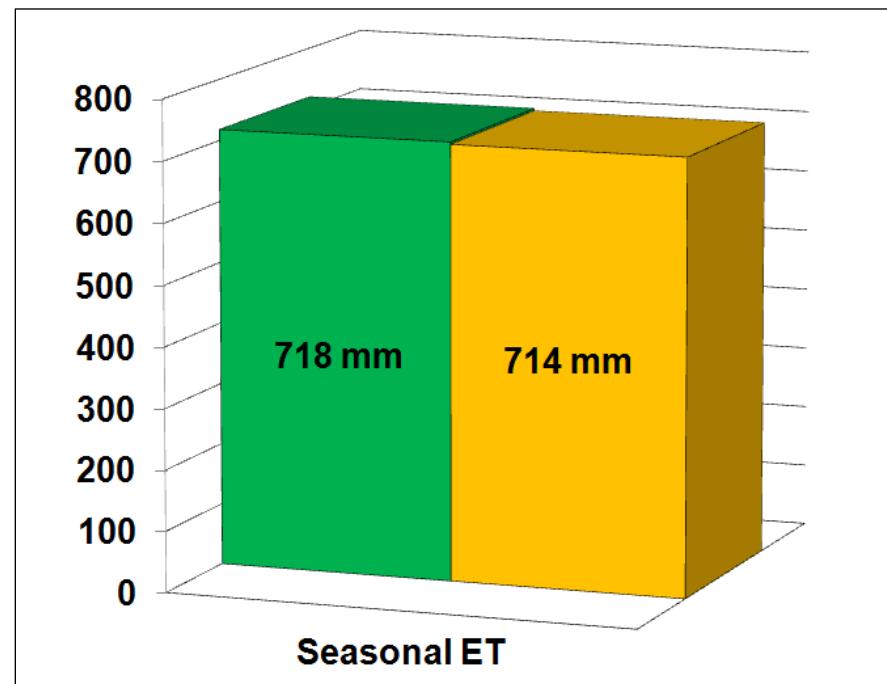


Growing-Season ET Estimation

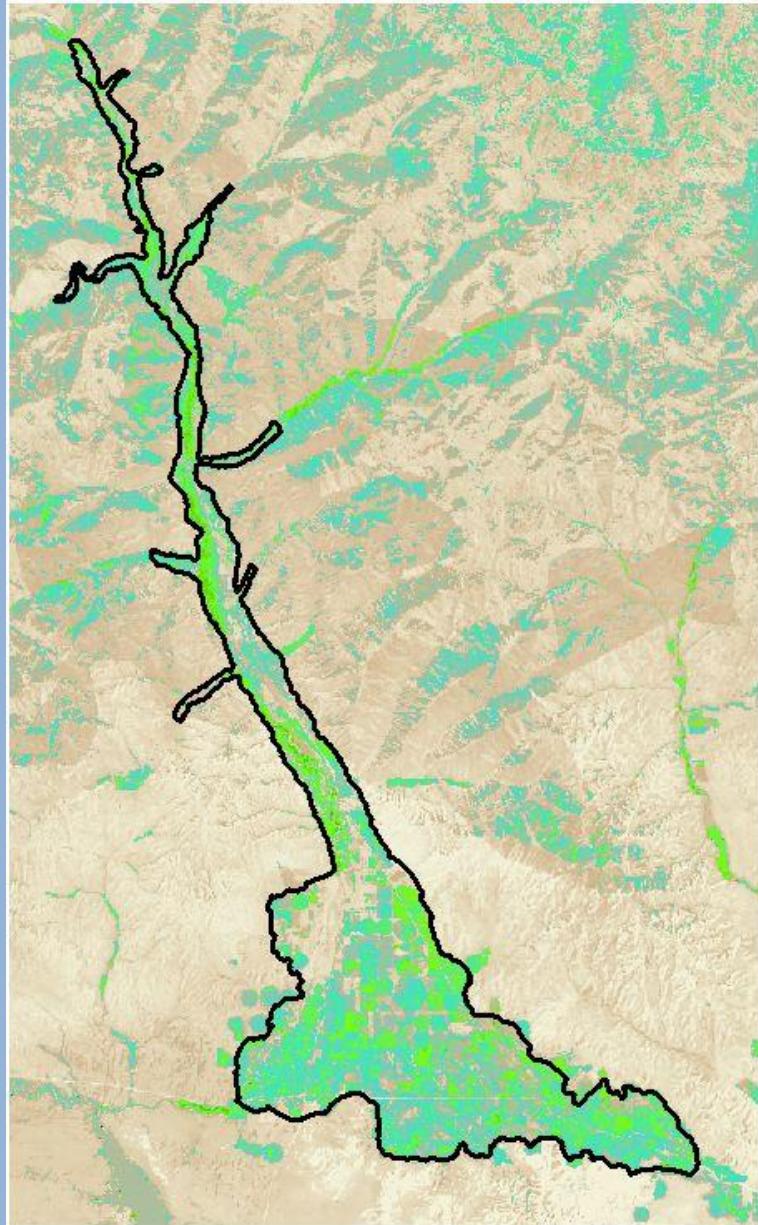
Growing-season ET estimates are based on remotely-sensed data.

METRIC is our best estimate of ET, and all growing-season ET estimates are related to METRIC.

Seasonal ET for sugar beets at
the Kimberly Research Station,
April to September, 1989.



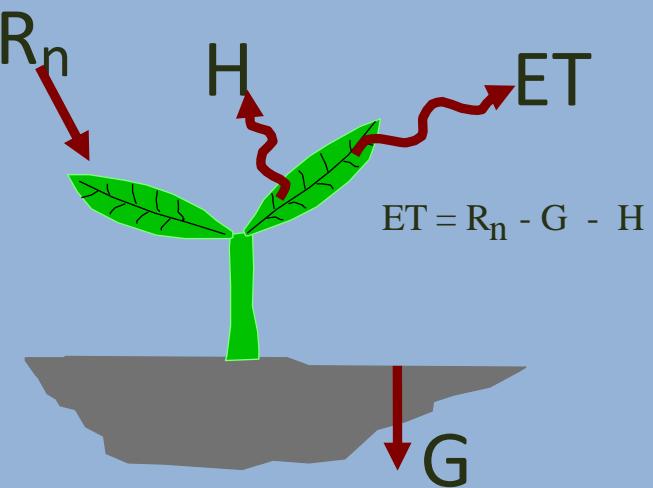
METRIC ET Estimation



METRIC ET is derived from remote sensing (satellite) data.

ET is calculated as a “residual” of the energy balance

The energy balance includes all major sources (R_n) and consumers (ET, G, H) of energy



Month	ET Estimation Method
Apr-95	
May-95	
Jun-95	
Jul-95	
Aug-95	
Sep-95	
Oct-95	
Apr-96	METRIC
May-96	METRIC
Jun-96	METRIC
Jul-96	METRIC
Aug-96	METRIC
Sep-96	METRIC
Oct-96	METRIC
Apr-97	
May-97	
Jun-97	
Jul-97	
Aug-97	
Sep-97	
Oct-97	
Apr-98	
May-98	
Jun-98	
Jul-98	
Aug-98	
Sep-98	
Oct-98	
Apr-99	
May-99	
Jun-99	
Jul-99	
Aug-99	
Sep-99	
Oct-99	
Apr-00	METRIC
May-00	METRIC
Jun-00	METRIC
Jul-00	METRIC
Aug-00	METRIC
Sep-00	METRIC
Oct-00	METRIC
Apr-01	
May-01	
Jun-01	
Jul-01	
Aug-01	
Sep-01	
Oct-01	
Apr-02	
May-02	
Jun-02	
Jul-02	
Aug-02	
Sep-02	
Oct-02	
Apr-03	
May-03	
Jun-03	
Jul-03	
Aug-03	
Sep-03	
Oct-03	
Apr-04	
May-04	
Jun-04	
Jul-04	
Aug-04	
Sep-04	
Oct-04	
Apr-05	
May-05	
Jun-05	
Jul-05	
Aug-05	
Sep-05	
Oct-05	
Apr-06	METRIC
May-06	METRIC
Jun-06	METRIC
Jul-06	METRIC
Aug-06	METRIC
Sep-06	METRIC
Oct-06	METRIC
Apr-07	
May-07	
Jun-07	
Jul-07	
Aug-07	
Sep-07	
Oct-07	
Apr-08	METRIC
May-08	METRIC
Jun-08	METRIC
Jul-08	METRIC
Aug-08	METRIC
Sep-08	METRIC
Oct-08	METRIC
Apr-09	METRIC
May-09	METRIC
Jun-09	METRIC
Jul-09	METRIC
Aug-09	METRIC
Sep-09	METRIC
Oct-09	METRIC
Apr-10	
May-10	
Jun-10	
Jul-10	
Aug-10	
Sep-10	
Oct-10	

METRIC is our best estimate of ET; however, it is not available for all months. Time and expense preclude METRIC_ET for some of the months, while clouds and smoke prevent the possibility of METRIC_ET for other months.

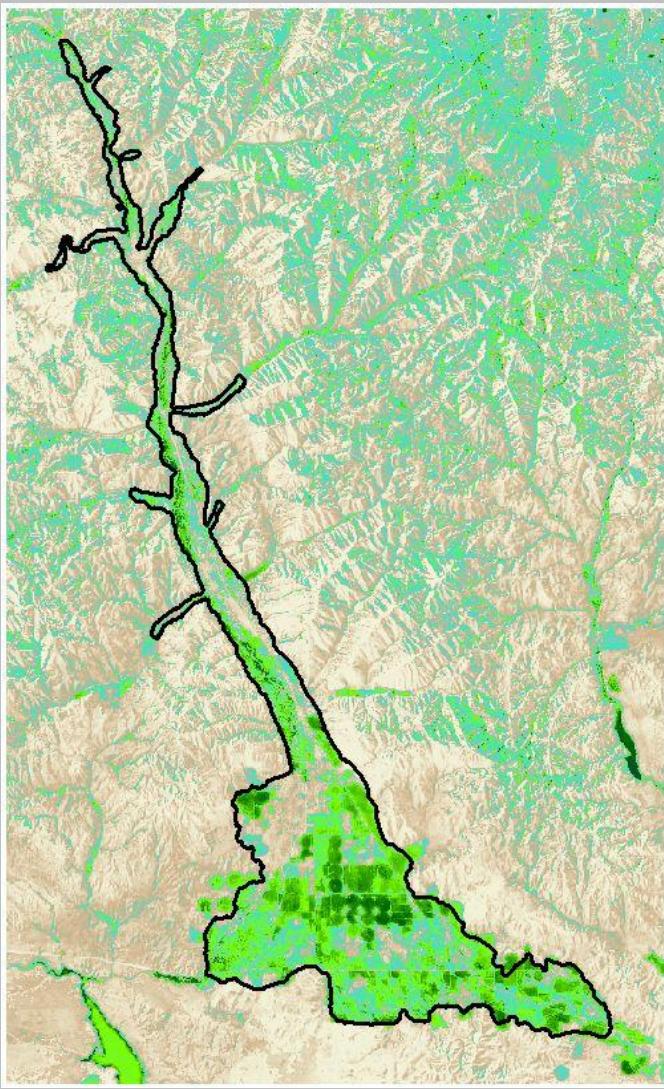
METRIC Limitation

Cloudy images can complicate or even prevent the use of METRIC.



Images with only partial cloud coverage can still be used.

Requires the use of a cloud-mask.

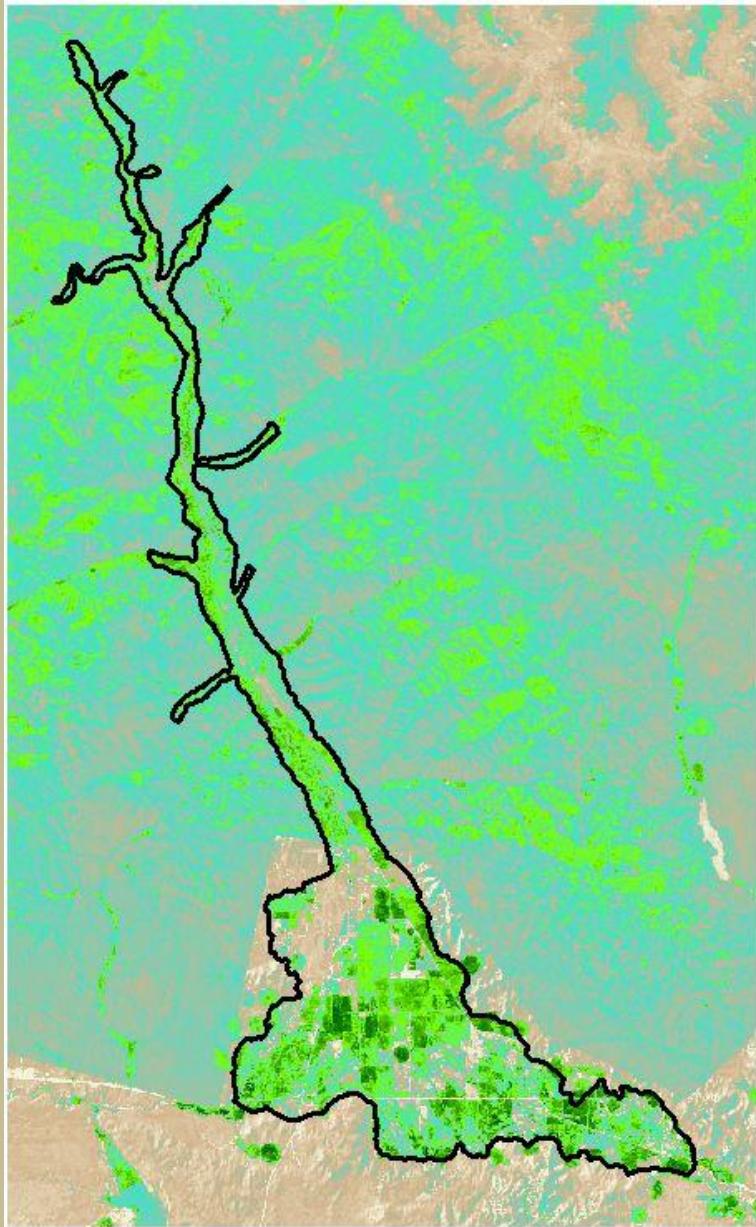


Cloud-free METRIC 07/2008.



Cloud-masked METRIC 04/1996.
April accounts for 10% of 1996 ET.
Masked area (northern portion) accounts
for 2% of 1996 ET.

ET Estimation: Growing Season 2002



07/2002

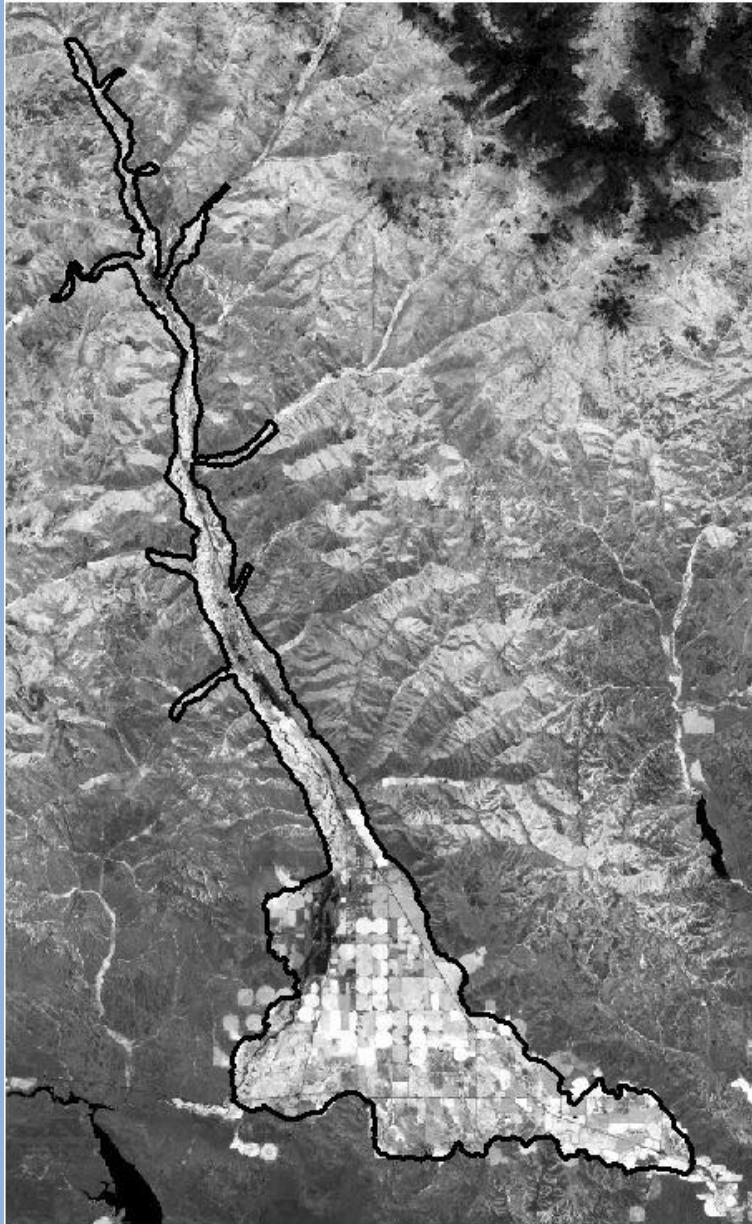
METRIC_ET is available for May – Oct, but only for the Bellevue triangle area. Use a correlation between METRIC and NDVI to estimate northern area ET.

1. Calculate NDVI_ET for the entire model area.
2. Compare NDVI_ET and METRIC_ET in Bellevue triangle.
3. Adjust NDVI_ET to match METRIC_ET in triangle.
4. Use adjusted NDVI_ET in northern area and METRIC_ET in triangle.

Month	ET Estimation Method	Month	ET Estimation Method	Month	ET Estimation Method	Month	ET Estimation Method
Apr-95		Apr-99		Apr-03		Apr-07	
May-95		May-99		May-03		May-07	
Jun-95		Jun-99		Jun-03		Jun-07	
Jul-95		Jul-99		Jul-03		Jul-07	
Aug-95		Aug-99		Aug-03		Aug-07	
Sep-95		Sep-99		Sep-03		Sep-07	
Oct-95		Oct-99		Oct-03		Oct-07	
Apr-96	METRIC	Apr-00	METRIC	Apr-04		Apr-08	METRIC
May-96	METRIC	May-00	METRIC	May-04		May-08	METRIC
Jun-96	METRIC	Jun-00	METRIC	Jun-04		Jun-08	METRIC
Jul-96	METRIC	Jul-00	METRIC	Jul-04		Jul-08	METRIC
Aug-96	METRIC	Aug-00	METRIC	Aug-04		Aug-08	METRIC
Sep-96	METRIC	Sep-00	METRIC	Sep-04		Sep-08	METRIC
Oct-96	METRIC	Oct-00	METRIC	Oct-04		Oct-08	METRIC
Apr-97		Apr-01		Apr-05		Apr-09	METRIC
May-97		May-01		May-05		May-09	METRIC
Jun-97		Jun-01		Jun-05		Jun-09	METRIC
Jul-97		Jul-01		Jul-05		Jul-09	METRIC
Aug-97		Aug-01		Aug-05		Aug-09	METRIC
Sep-97		Sep-01		Sep-05		Sep-09	METRIC
Oct-97		Oct-01		Oct-05		Oct-09	METRIC
Apr-98		Apr-02		Apr-06	METRIC	Apr-10	
May-98		May-02	Correlated Upper Valley	May-06	METRIC	May-10	
Jun-98		Jun-02	Correlated Upper Valley	Jun-06	METRIC	Jun-10	
Jul-98		Jul-02	Correlated Upper Valley	Jul-06	METRIC	Jul-10	
Aug-98		Aug-02	Correlated Upper Valley	Aug-06	METRIC	Aug-10	
Sep-98		Sep-02	Correlated Upper Valley	Sep-06	METRIC	Sep-10	
Oct-98		Oct-02	Correlated Upper Valley	Oct-06	METRIC	Oct-10	

METRIC_ET is available for part of the model area during May – Oct 2002. Use correlated data for a complete data set.

NDVI_ET Estimation



07/2010

NDVI_ET uses a regression equation to relate NDVI values and the ET fraction from METRIC (ETrF).

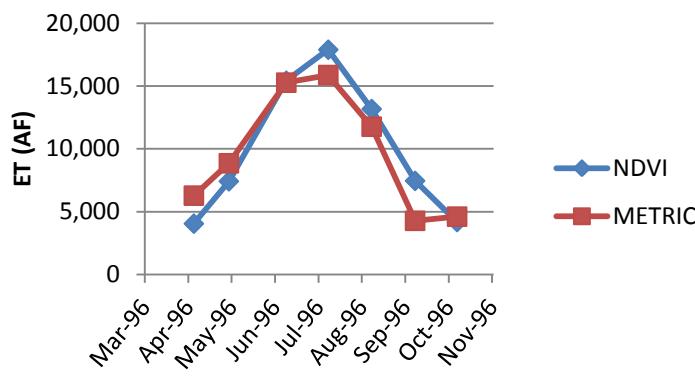
$$\text{ETrF} = 0.15 + 1.06 \text{ NDVI}$$

The ETrF is then combined with weather data (as is done in METRIC) to produce ET. Reference ET (ETr) is the max ET from a perfect alfalfa crop.

$$\text{ET} = \text{ETrF} \times \text{ETr}$$

NDVI_ET estimates are approximately 9% higher on average than METRIC_ET for areas and times when both values are available.

Irrigated ET 1996

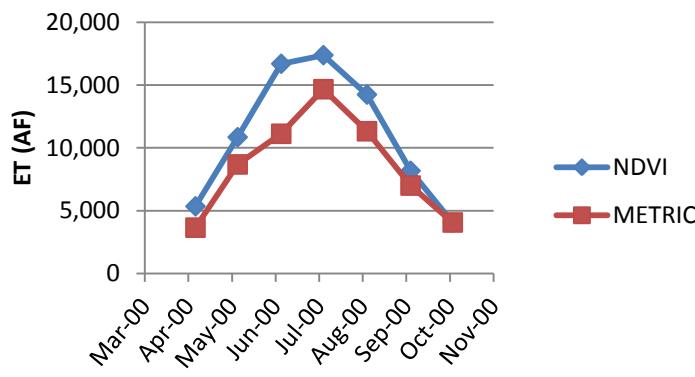


METRIC Vs NDVI

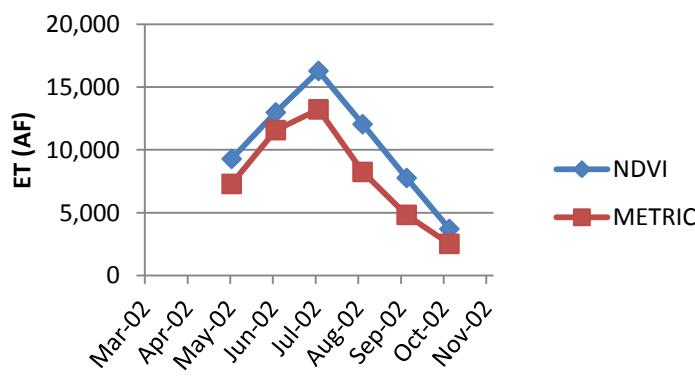
NDVI generally estimates more ET than METRIC.

NDVI is approximately 9% higher than METRIC over the entire concurrent period of record.

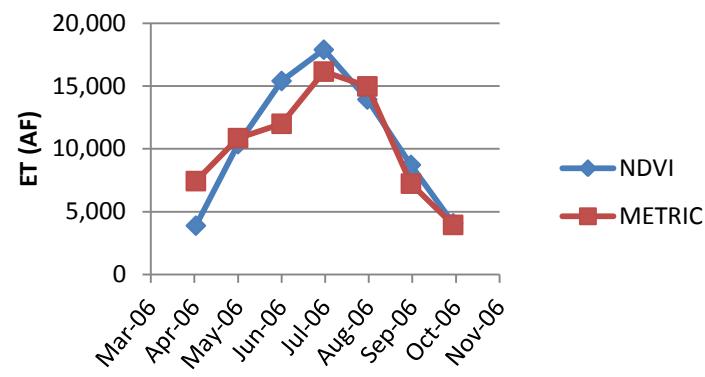
Irrigated ET 2000



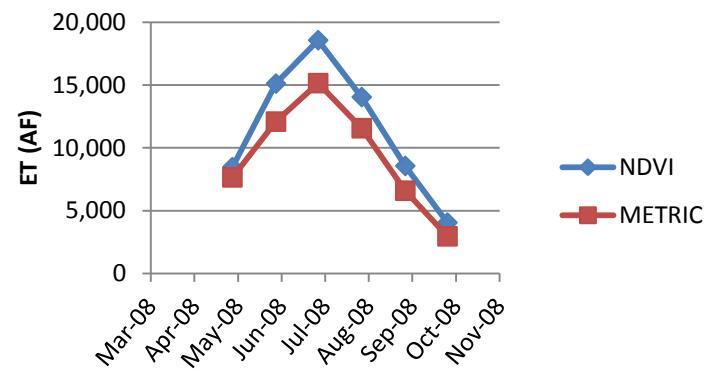
Irrigated ET 2002



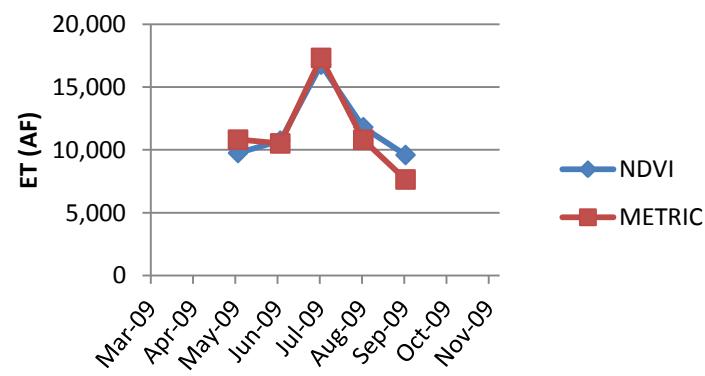
Irrigated ET 2006



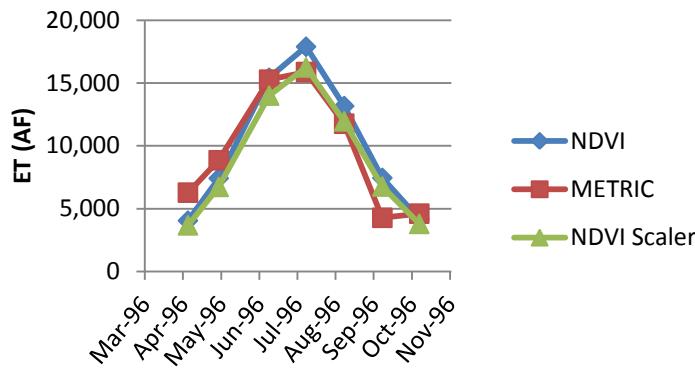
Irrigated ET 2008



Irrigated ET 2009

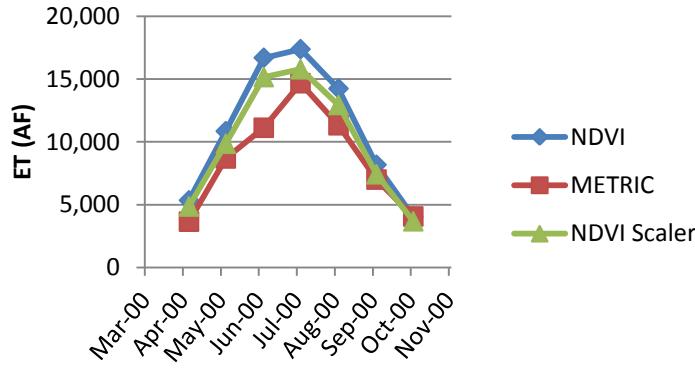


Irrigated ET 1996



9%
Scalar
Adjustment

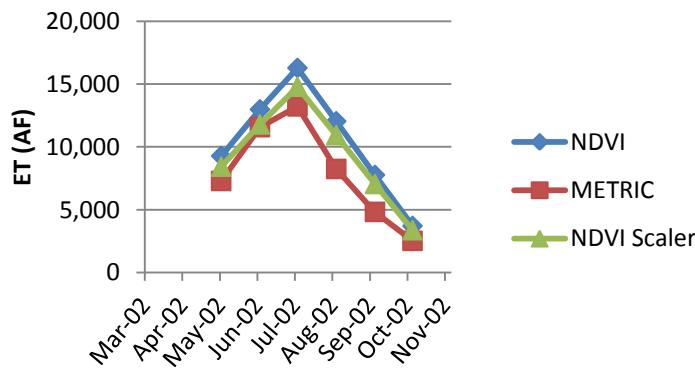
Irrigated ET 2000



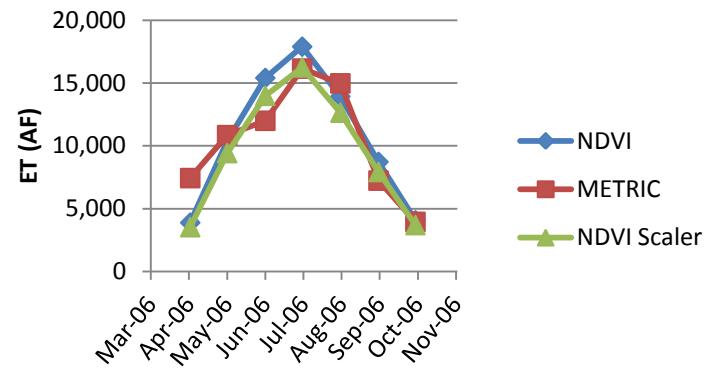
Green lines on
charts are
Adjusted NDVI.

NDVI values
adjusted down
by 9%.

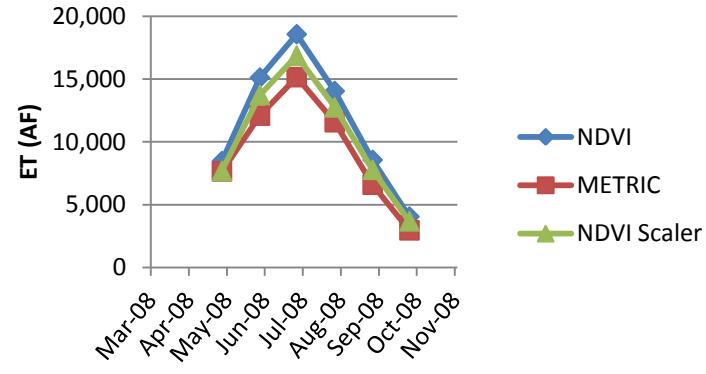
Irrigated ET 2002



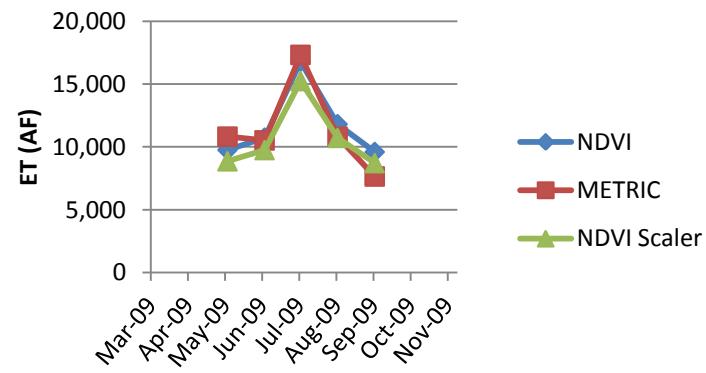
Irrigated ET 2006



Irrigated ET 2008

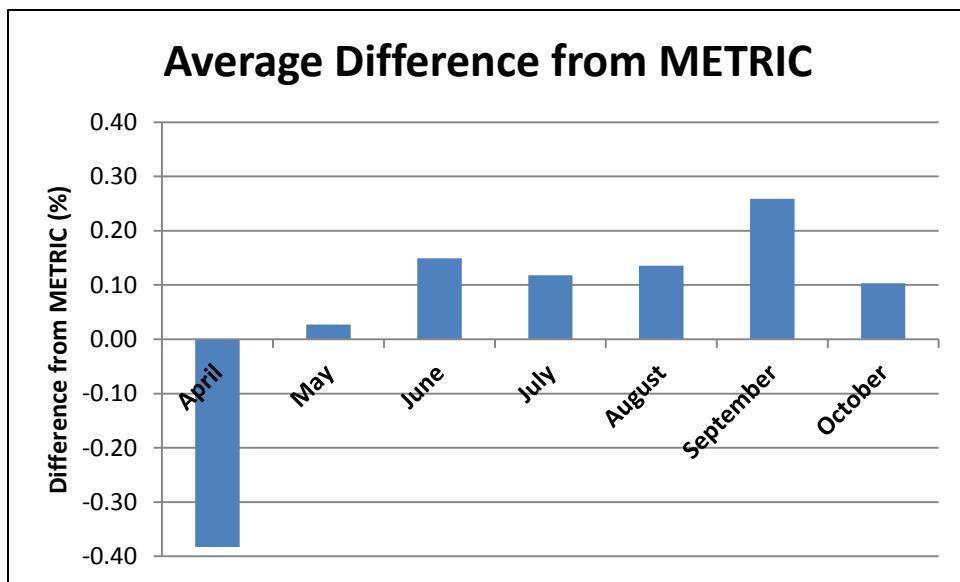


Irrigated ET 2009



Month Specific Adjustments to NDVI

Using a scalar adjustment may create bigger differences between estimations for April.

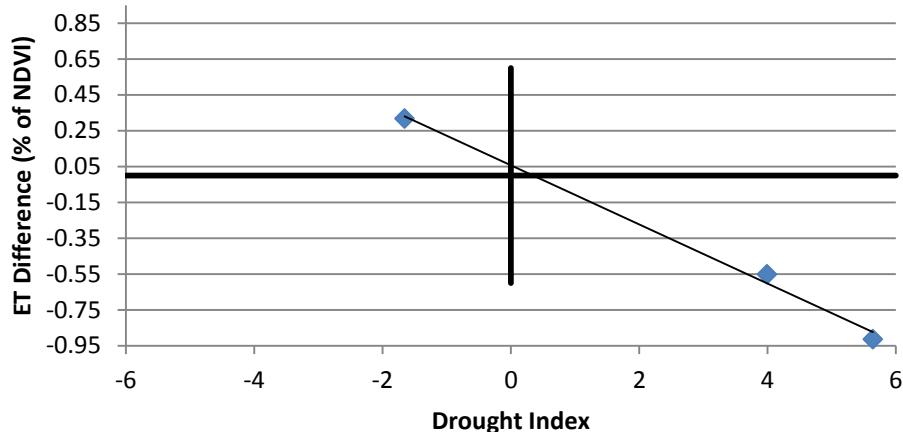


Remember these averages are based on only a few data points.

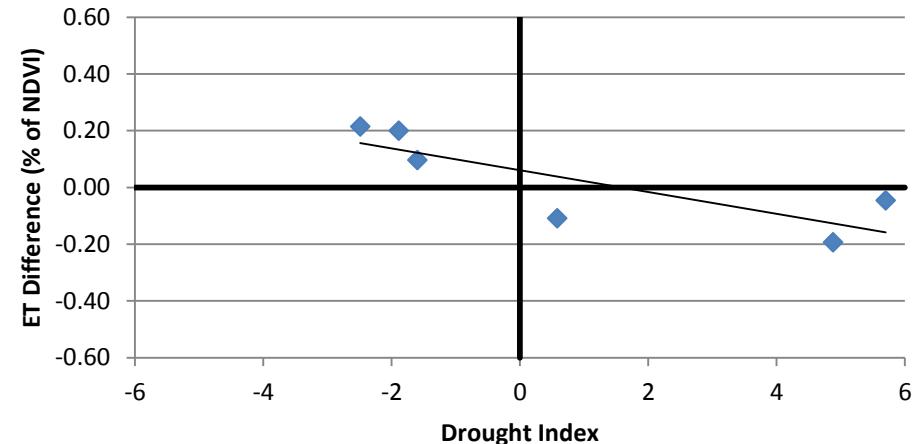
Month Specific Adjustments to NDVI- Drought Index

Monthly differences seem to be correlated with precipitation – especially in the spring.

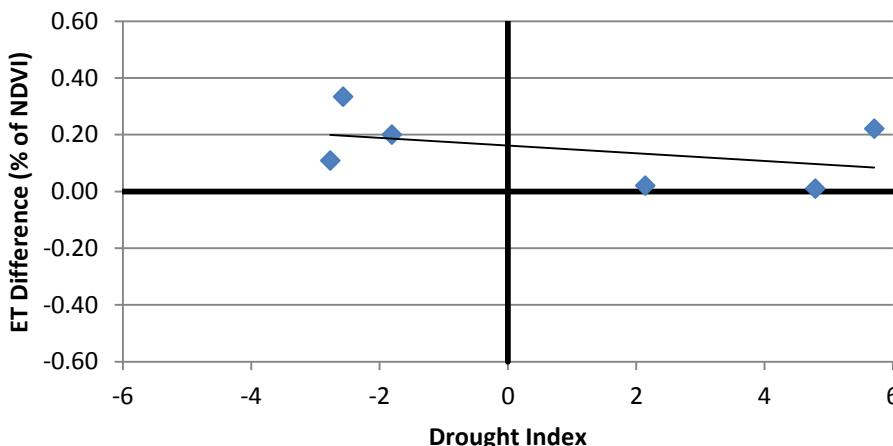
April



May



June



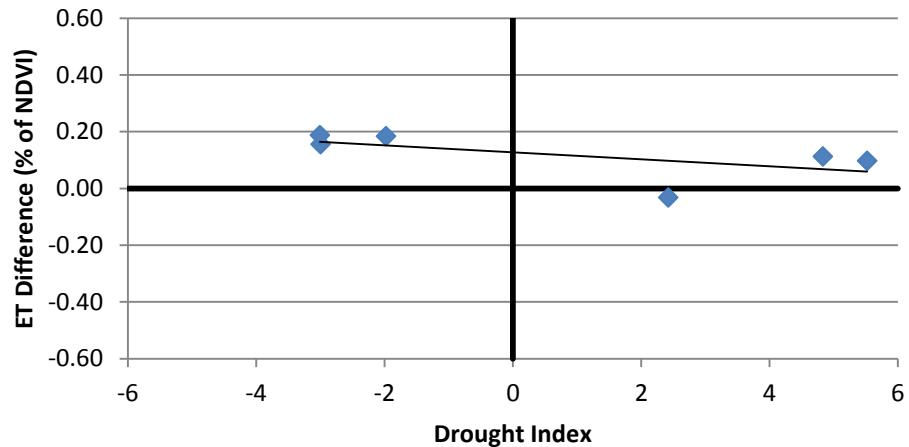
The character of the differences between estimates match expectations based on the development of the methods.

(very few data)

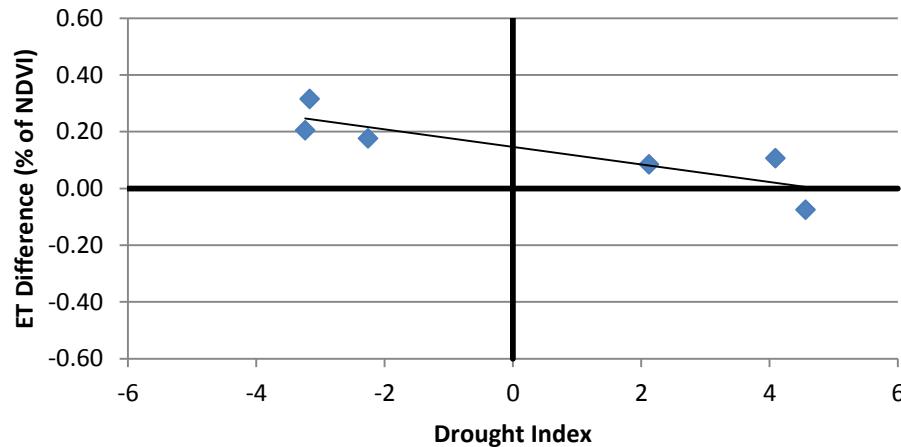
Month Specific Adjustments to NDVI- Drought Index

Monthly differences seem to be correlated with precipitation – especially in the spring.

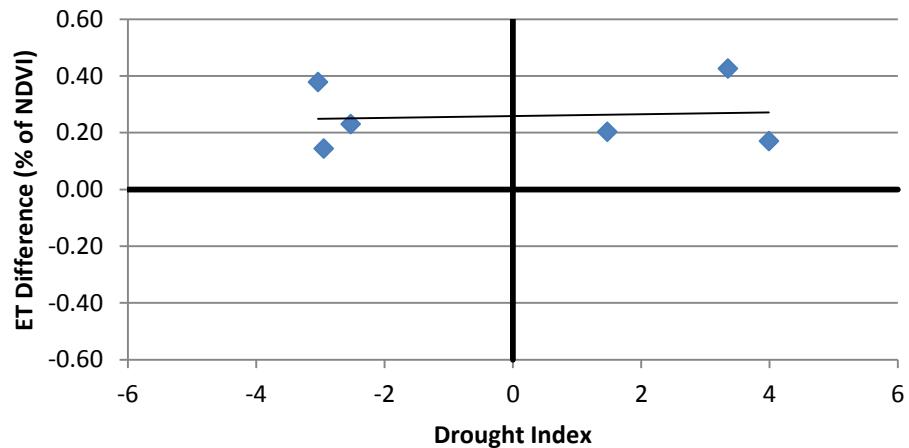
July



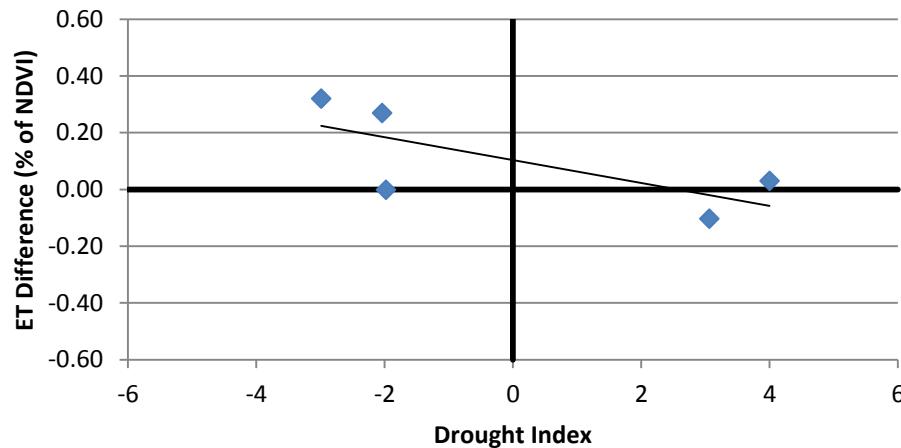
August



September



October



Month Specific Adjustments to NDVI

Although differences in ET appear to be correlated with precipitation, and the difference match expectations, there are few data .

Therefore, a scalar adjustment of 9% has been applied to all NDVI data.

The regression equation used to relate NDVI values and the ET fraction from METRIC (ETrF) was derived for average rainfall conditions.

Propose to use seasonal wet/dry regression equations as a next-round improvement.

Month	ET Estimation Method
Apr-95	
May-95	
Jun-95	
Jul-95	NDVI
Aug-95	
Sep-95	
Oct-95	
Apr-96	METRIC
May-96	METRIC
Jun-96	METRIC
Jul-96	METRIC
Aug-96	METRIC
Sep-96	METRIC
Oct-96	METRIC
Apr-97	
May-97	
Jun-97	
Jul-97	
Aug-97	
Sep-97	NDVI
Oct-97	NDVI
Apr-98	
May-98	
Jun-98	
Jul-98	
Aug-98	NDVI
Sep-98	NDVI
Oct-98	NDVI
Apr-99	
May-99	
Jun-99	
Jul-99	
Aug-99	NDVI
Sep-99	NDVI
Oct-99	NDVI
Apr-00	METRIC
May-00	METRIC
Jun-00	METRIC
Jul-00	METRIC
Aug-00	METRIC
Sep-00	METRIC
Oct-00	METRIC
Apr-01	
May-01	
Jun-01	NDVI
Jul-01	NDVI
Aug-01	NDVI
Sep-01	NDVI
Oct-01	NDVI
Apr-02	
May-02	Correlated Upper Valley
Jun-02	Correlated Upper Valley
Jul-02	Correlated Upper Valley
Aug-02	Correlated Upper Valley
Sep-02	Correlated Upper Valley
Oct-02	Correlated Upper Valley
Apr-03	
May-03	
Jun-03	NDVI
Jul-03	NDVI
Aug-03	NDVI
Sep-03	NDVI
Oct-03	
Apr-04	NDVI
May-04	
Jun-04	
Jul-04	NDVI
Aug-04	
Sep-04	
Oct-04	NDVI
Apr-05	NDVI
May-05	NDVI
Jun-05	NDVI
Jul-05	NDVI
Aug-05	NDVI
Sep-05	NDVI
Oct-05	NDVI
Apr-06	METRIC
May-06	METRIC
Jun-06	METRIC
Jul-06	METRIC
Aug-06	METRIC
Sep-06	METRIC
Oct-06	METRIC
Apr-07	NDVI
May-07	NDVI
Jun-07	NDVI
Jul-07	NDVI
Aug-07	NDVI
Sep-07	NDVI
Oct-07	NDVI
Apr-08	METRIC
May-08	METRIC
Jun-08	METRIC
Jul-08	METRIC
Aug-08	METRIC
Sep-08	METRIC
Oct-08	METRIC
Apr-09	METRIC
May-09	METRIC
Jun-09	METRIC
Jul-09	METRIC
Aug-09	METRIC
Sep-09	METRIC
Oct-09	METRIC
Apr-10	
May-10	
Jun-10	
Jul-10	
Aug-10	
Sep-10	
Oct-10	

For months with cloud-free images and no METRIC, use NDVI to estimate ET.

ET Estimation by Interpolation

$$\begin{array}{ll} \textbf{METRIC_ET} = \text{ET Fraction} \times \text{Reference ET} & \rightarrow \quad \textbf{METRIC_ET} = ETrF \times ETr \\ \textbf{NDVI_ET} = \text{ET Fraction} \times \text{Reference ET} & \rightarrow \quad \textbf{NDVI_ET} = Kc \times ETr \end{array}$$

Example:

Need: ET June 2004

Have: NDVI July 2004

Have: Reference ET (ETr) for June 2004 from weather station

Have: METRIC June and July 2006

Have: NDVI June and July 2006

1. Divide July 2004 Crop Coef. by July 2006 Crop Coef. to get ratio of July Kc's.

$$Kc_{Jul2004} / Kc_{Jul2006} = \text{ratio}_{04/06}$$

(assume ratio applies to June)

2. Multiply June 2006 ET Fraction by the ratio of July Kc. To get interpolated ETrF.

$$ETrF_{Jun2006} \times \text{ratio}_{04/06} = ETrF_{Jun2004_INT}$$

3. Multiply Interpolated ETrF by June 2004 Reference ET from weather stations to get interpolated June 2004 ET.

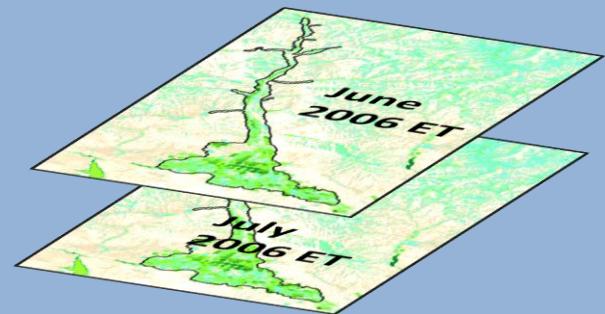
$$ETrF_{Jun_INT} \times ETr_{Jun2004} = INT_ET_{Jun2004}$$

ET Estimation by Interpolation

2004

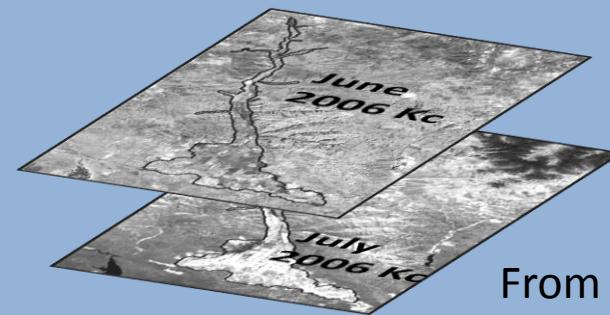


2006



METRIC

From NDVI

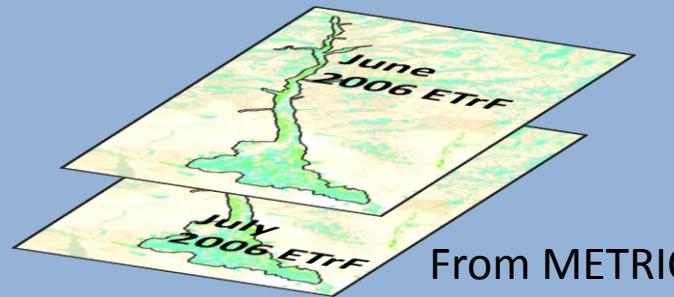


From NDVI

June 2004 ETr

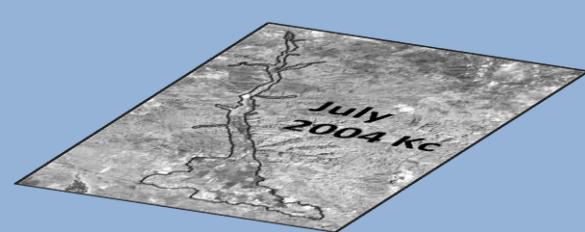


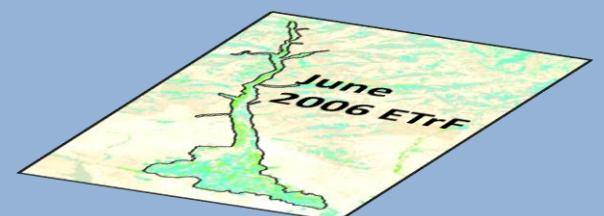
From Weather
Station



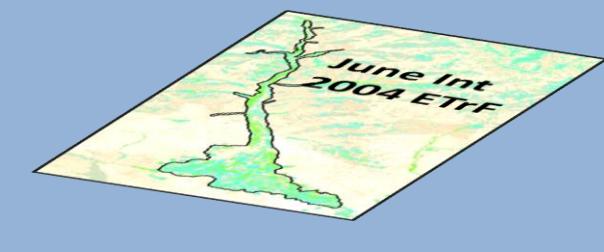
From METRIC

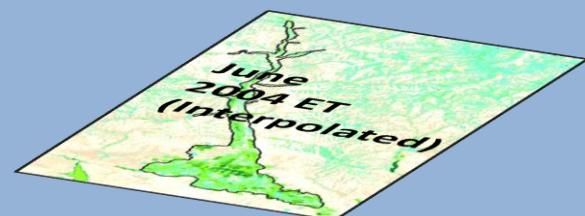
ET Estimation by Interpolation


$$\div = \text{Ratio}_{04/06}$$


$$\times \text{Ratio}_{04/06} =$$



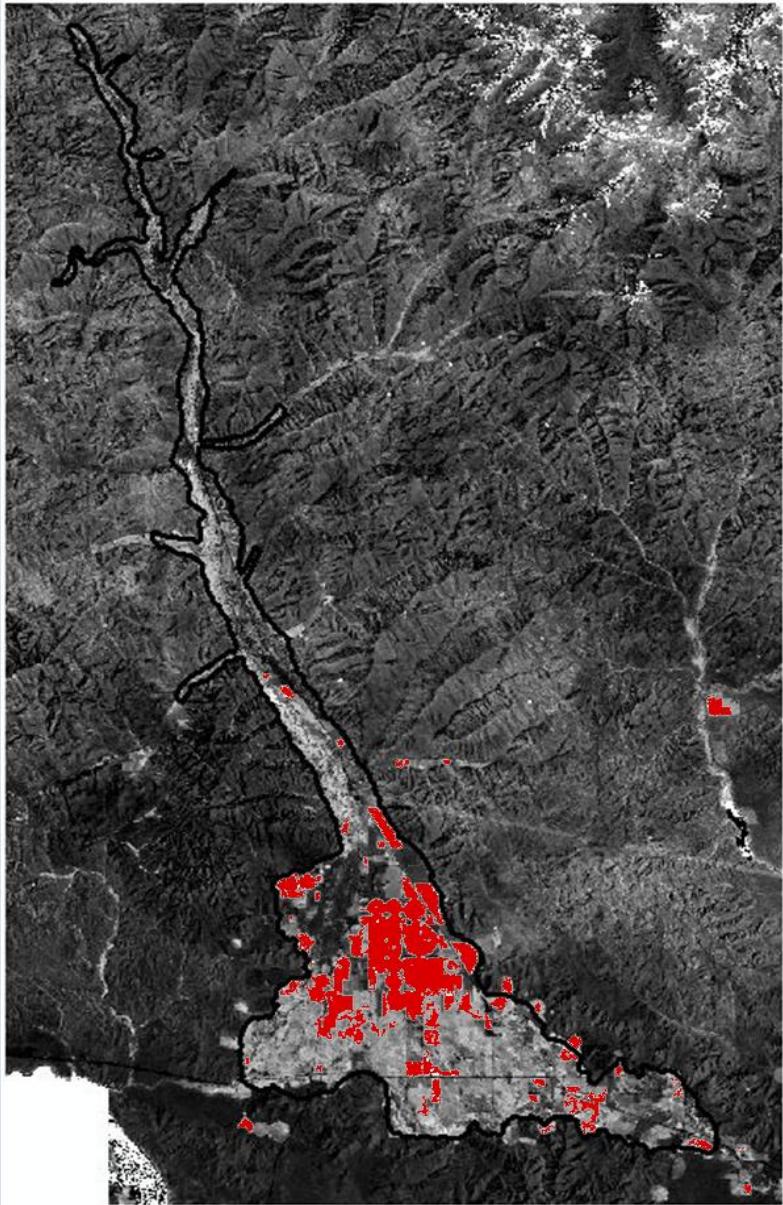

$$\times =$$



Month	ET Estimation Method	Month	ET Estimation Method	Month	ET Estimation Method	Month	ET Estimation Method
Apr-95	Interpolated	Apr-99	Interpolated	Apr-03	Interpolated	Apr-07	NDVI
May-95	Interpolated	May-99	Interpolated	May-03	Interpolated	May-07	NDVI
Jun-95	Interpolated	Jun-99	Interpolated	Jun-03	NDVI	Jun-07	NDVI
Jul-95	NDVI	Jul-99	Interpolated	Jul-03	NDVI	Jul-07	NDVI
Aug-95	Interpolated	Aug-99	NDVI	Aug-03	NDVI	Aug-07	NDVI
Sep-95	Interpolated	Sep-99	NDVI	Sep-03	NDVI	Sep-07	NDVI
Oct-95	Interpolated	Oct-99	NDVI	Oct-03	Interpolated	Oct-07	NDVI
Apr-96	METRIC	Apr-00	METRIC	Apr-04	NDVI	Apr-08	METRIC
May-96	METRIC	May-00	METRIC	May-04		May-08	METRIC
Jun-96	METRIC	Jun-00	METRIC	Jun-04		Jun-08	METRIC
Jul-96	METRIC	Jul-00	METRIC	Jul-04	NDVI	Jul-08	METRIC
Aug-96	METRIC	Aug-00	METRIC	Aug-04	Interpolated	Aug-08	METRIC
Sep-96	METRIC	Sep-00	METRIC	Sep-04	Interpolated	Sep-08	METRIC
Oct-96	METRIC	Oct-00	METRIC	Oct-04	NDVI	Oct-08	METRIC
Apr-97		Apr-01		Apr-05	NDVI	Apr-09	METRIC
May-97		May-01		May-05	NDVI	May-09	METRIC
Jun-97		Jun-01	NDVI	Jun-05	NDVI	Jun-09	METRIC
Jul-97		Jul-01	NDVI	Jul-05	NDVI	Jul-09	METRIC
Aug-97		Aug-01	NDVI	Aug-05	NDVI	Aug-09	METRIC
Sep-97	NDVI	Sep-01	NDVI	Sep-05	NDVI	Sep-09	METRIC
Oct-97	NDVI	Oct-01	NDVI	Oct-05	NDVI	Oct-09	METRIC
Apr-98		Apr-02	Interpolated	Apr-06	METRIC	Apr-10	Interpolated
May-98		May-02	Correlated Upper Valley	May-06	METRIC	May-10	Interpolated
Jun-98		Jun-02	Correlated Upper Valley	Jun-06	METRIC	Jun-10	Interpolated
Jul-98		Jul-02	Correlated Upper Valley	Jul-06	METRIC	Jul-10	Interpolated
Aug-98	NDVI	Aug-02	Correlated Upper Valley	Aug-06	METRIC	Aug-10	Interpolated
Sep-98	NDVI	Sep-02	Correlated Upper Valley	Sep-06	METRIC	Sep-10	Interpolated
Oct-98	NDVI	Oct-02	Correlated Upper Valley	Oct-06	METRIC	Oct-10	Interpolated

For months without satellite data, interpolate from months with known ET values.

Adjusted Interpolation



Interpolation works well for most months and most of the land uses. Changes in crop vigor are well represented by the ratio of Kc values for fully vegetated areas. However, sometimes the technique is confounded by drastic changes in land use.

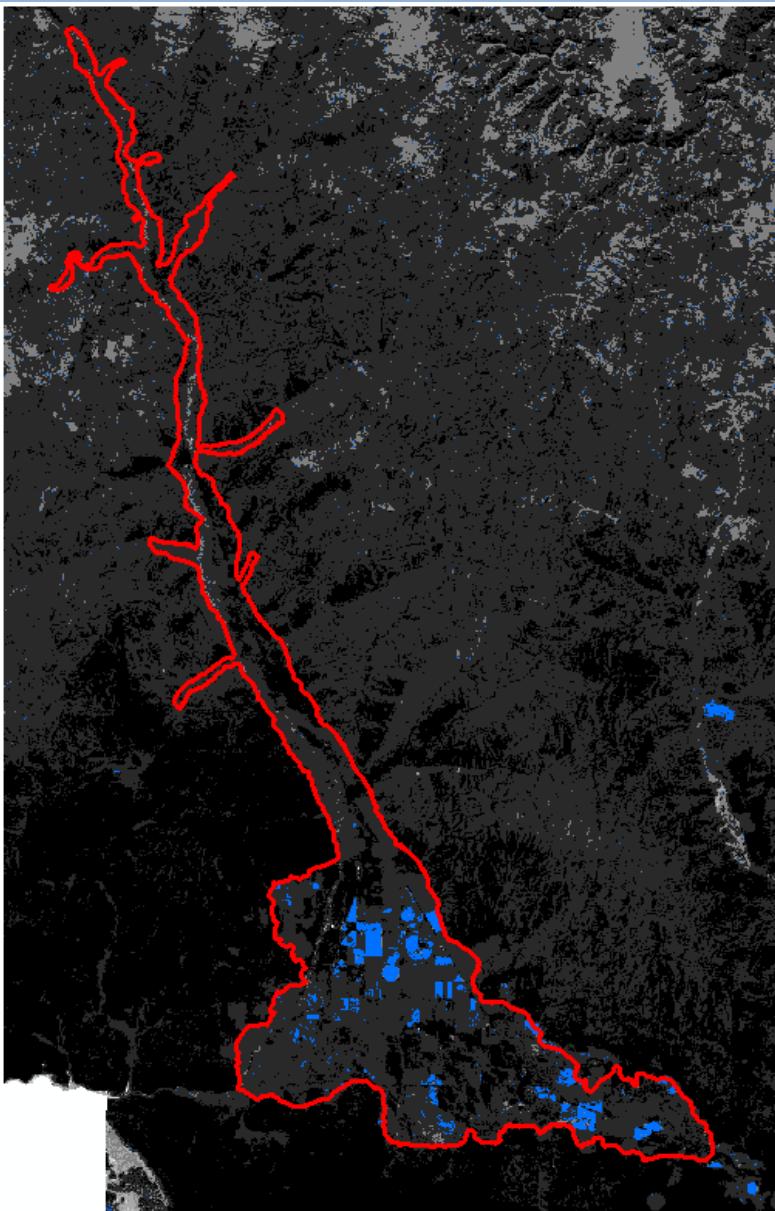
Example:

If the METRIC source year has fields that were cut (alfalfa) or fallow (insufficient water supply) when the satellite passed, the interpolated values will be much too high.

Adjusted excessive ET on cultivated crops by limiting to maximum alfalfa ET.

07/1997

Options to Adjusted Interpolation

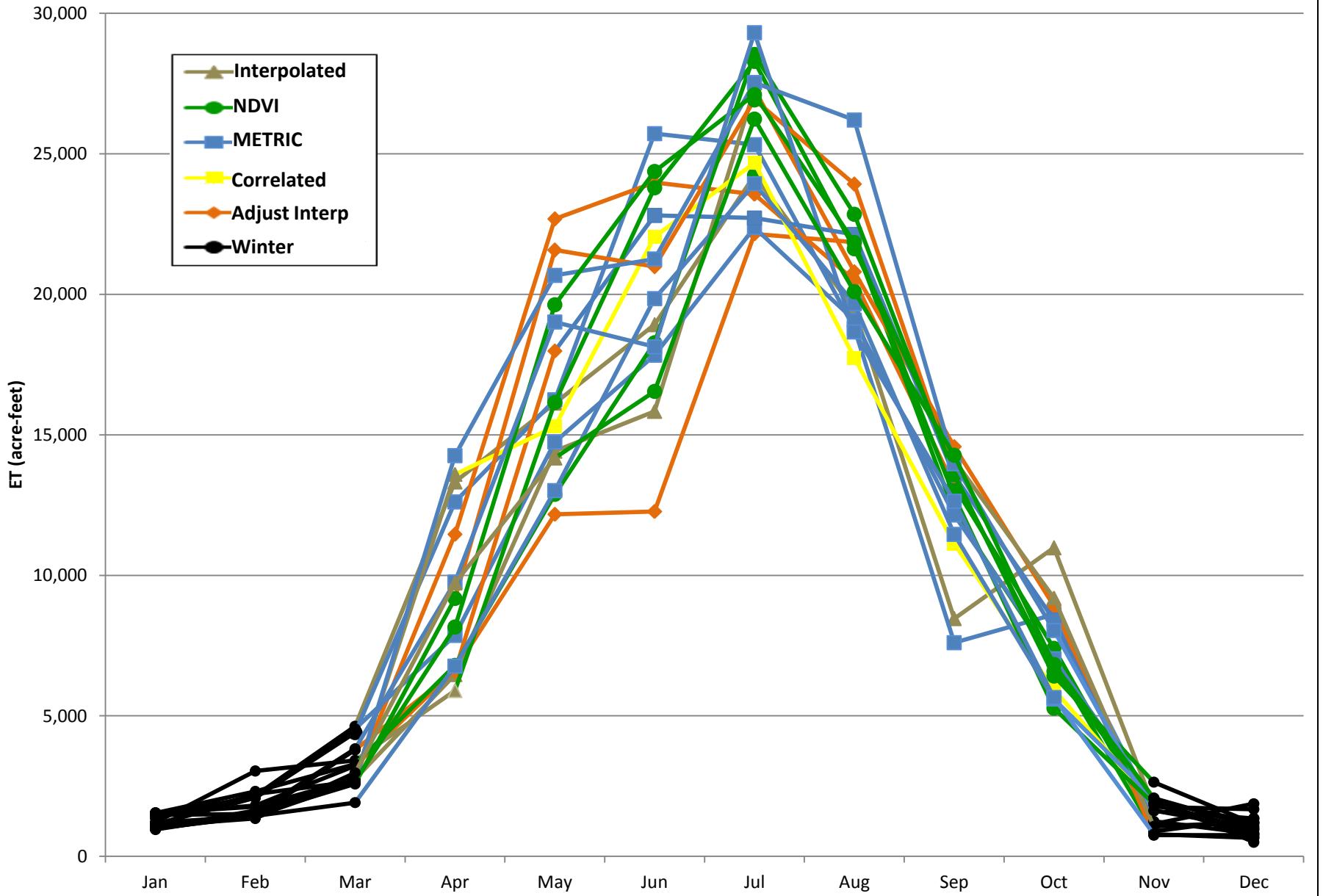


- Place upper bound on interpolated ETrF.
 - For Wood River Valley I chose Alfalfa Kc.
 - Determine land use for upper bound.
- Use average of source years for ETrF.
- Use more distant source year for ETrF.
- Use traditional calculation based on land use.
 - nlcd or cdl for land use.
 - County crop mix reports.
 - Crop mix based on NDVI.
- Other ideas?
 - Land use is a big issue, avoid if possible.

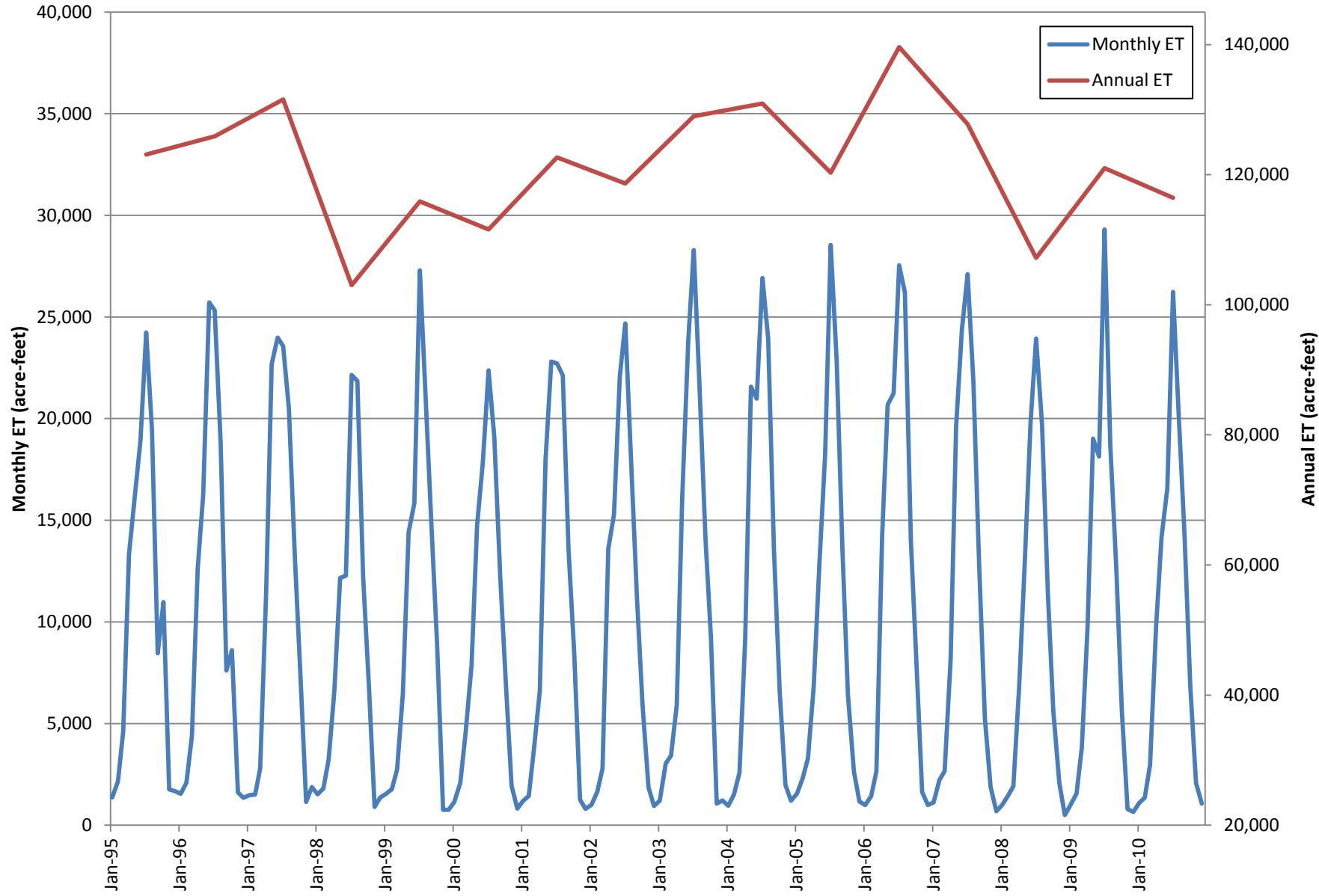
Month	ET Estimation Method
Apr-95	Interpolated
May-95	Interpolated
Jun-95	Interpolated
Jul-95	NDVI
Aug-95	Interpolated
Sep-95	Interpolated
Oct-95	Interpolated
Apr-96	METRIC
May-96	METRIC
Jun-96	METRIC
Jul-96	METRIC
Aug-96	METRIC
Sep-96	METRIC
Oct-96	METRIC
Apr-97	Adjusted Interpolation
May-97	Adjusted Interpolation
Jun-97	Adjusted Interpolation
Jul-97	Adjusted Interpolation
Aug-97	Adjusted Interpolation
Sep-97	NDVI
Oct-97	NDVI
Apr-98	Adjusted Interpolation
May-98	Adjusted Interpolation
Jun-98	Adjusted Interpolation
Jul-98	Adjusted Interpolation
Aug-98	NDVI
Sep-98	NDVI
Oct-98	NDVI
Apr-99	Interpolated
May-99	Interpolated
Jun-99	Interpolated
Jul-99	Interpolated
Aug-99	NDVI
Sep-99	NDVI
Oct-99	NDVI
Apr-00	METRIC
May-00	METRIC
Jun-00	METRIC
Jul-00	METRIC
Aug-00	METRIC
Sep-00	METRIC
Oct-00	METRIC
Apr-01	Adjusted Interpolation
May-01	Adjusted Interpolation
Jun-01	NDVI
Jul-01	NDVI
Aug-01	NDVI
Sep-01	NDVI
Oct-01	NDVI
Apr-02	Interpolated
May-02	Correlated Upper Valley
Jun-02	Correlated Upper Valley
Jul-02	Correlated Upper Valley
Aug-02	Correlated Upper Valley
Sep-02	Correlated Upper Valley
Oct-02	Correlated Upper Valley
Apr-03	Interpolated
May-03	Interpolated
Jun-03	NDVI
Jul-03	NDVI
Aug-03	NDVI
Sep-03	NDVI
Oct-03	Interpolated
Apr-04	NDVI
May-04	Adjusted Interpolation
Jun-04	Adjusted Interpolation
Jul-04	NDVI
Aug-04	Interpolated
Sep-04	Interpolated
Oct-04	NDVI
Apr-05	NDVI
May-05	NDVI
Jun-05	NDVI
Jul-05	NDVI
Aug-05	NDVI
Sep-05	NDVI
Oct-05	NDVI
Apr-06	METRIC
May-06	METRIC
Jun-06	METRIC
Jul-06	METRIC
Aug-06	METRIC
Sep-06	METRIC
Oct-06	METRIC
Apr-07	NDVI
May-07	NDVI
Jun-07	NDVI
Jul-07	NDVI
Aug-07	NDVI
Sep-07	NDVI
Oct-07	NDVI
Apr-08	METRIC
May-08	METRIC
Jun-08	METRIC
Jul-08	METRIC
Aug-08	METRIC
Sep-08	METRIC
Oct-08	METRIC
Apr-09	METRIC
May-09	METRIC
Jun-09	METRIC
Jul-09	METRIC
Aug-09	METRIC
Sep-09	METRIC
Oct-09	METRIC
Apr-10	Interpolated
May-10	Interpolated
Jun-10	Interpolated
Jul-10	Interpolated
Aug-10	Interpolated
Sep-10	Interpolated
Oct-10	Interpolated

All growing-season ET is derived from remote sensing (satellite) data. Different methods have been employed to obtain satellite-based ET estimates for every month.

Big Wood ET - By Estimation Method



Big Wood Total ET





Department of
Water Resources



Discussion.

PDSI

